IAU Symp. 198 : The Light Elements and their Evolution
ASP Conference Series, Vol. ..., 2000
L. da Silva, R. de Medeiros, M. Spite, eds

Sinks of Light Elements in Stars – Part III

Corinne Charbonnel

Laboratoire d'Astrophysique de l'Observatoire Midi-Pyrénées, CNRS-UMR 5572, 14, av.E.Belin, F-31400 Toulouse, France

Constantine P. Deliyannis

Indiana University, Astronomy Department, 319 Swain Hall West, 727 E. 3rd Street, Bloomington, IN 47405-7105, USA

Marc Pinsonneault

The Ohio State University, Department of Astronomy, 140 W. 18th Ave., Columbus, OH 43210, USA

Abstract. See the abstract given in Part I (Deliyannis, Pinsonneault, Charbonnel, hereafter DPC, this volume). In Part III, we first discuss the LiBeB observations in subgiant stars and the constraints they bring on the transport processes occuring on the main sequence. Evidence is then reviewed that suggests that in situ mixing occurs in evolved low mass Population I and Population II stars. Theoretical mechanisms that can create such mixing are discussed, as well as their implications for the evolution of the LiBeB and ^{3}He.

1. Introduction

Evolved stars can be important sinks for light elements. In Parts I and II we reviewed the observational and theoretical situation for Population I and Population II main sequence stars. The structural evolution of evolved low mass stars is different than their main sequence precursors. The surface abundances are diluted as stars travel from the main sequence across the subgiant branch to the red giant branch. This first dredge-up is completed when the surface convection zone reaches its maximum depth in mass (below the luminosity of the horizontal branch). The properties of stars as they undergo the first dredge-up can provide clues about the internal abundance profiles of their main sequence precursors; we review the conclusions that can be drawn from subgiants in §2. On the upper giant branch standard models - which predict constant surface abundances after the completion of the first dregdge-up - are in serious conflict with the observational data, which exhibits strong trends with increased luminosity; we discuss first-ascent red giants in §3.

2. LiBeB on the subgiant branch - Constraints for the processes occuring on the main sequence

2.1. Population I subgiants

LiBeB abundances in subgiants are *a posteriori* tracers of the hydrodynamical processes that affect these elements during the previous evolutionary phases. Indeed, when the first dredge-up occurs, the convective dilution of the external stellar layers with the internal LiBeB free regions induces a decrease of the surface abundances down to values that depend on the stellar mass and metallicity (which dictate the dredge-up efficiency) and on the total LiBeB content in the star at the turnoff. One thus expects very low post-dilution abundances for stars which significantly destroyed these elements during the pre-main sequence and the main sequence. This is the case in particular for Li in Pop I evolved stars with initial masses lower than about $1.4M_\odot$ for which the large Li dispersion reflects the distribution on the main sequence and at the turnoff (see DPC).

Until recently, the situation was less clear for the more massive stars (A and early-F types) which spend their main sequence on the hot side of the Li-dip (note that there are strong observational selection effects for the hotter stars which are rapidly rotating and for which lithium abundances can not be measured). In open clusters like Coma, Praesepe and the Hyades, these stars show Li abundances close to the galactic value, except for some Li deficient Am stars (Boesgaard 1987; Burkhart & Coupry 1989, 1998, 2000). However, important Li underabundances are exhibited by some of their field main sequence or slightly evolved counterparts before the dilution starts (Alschuler 1975, Brown et al. 1989, Balachandran 1990, Wallerstein et al. 1994). This, in addition to the fact that dilution alone can not explain the low lithium values shown by the giants in the open clusters with turnoff masses higher than $\sim 1.5M_\odot$ (Gilroy 1989, Charbonneau et al. 1989; see Figure 1) suggested that some Li depletion occurs inside these stars while they are on the main sequence but shows up at the surface relatively late (i.e., still on the main sequence but after the age of the Hyades) compared to cooler dwarfs (Vauclair 1991, Charbonnel & Vauclair 1992). This was confirmed by Randich et al. (1999) and do Nascimento et al. (2000, using data by Lèbre et al. 1999) on the basis of the spectroscopic analysis of large samples of field Pop I subgiants for which Hipparcos data allowed the precise determination of both the mass and evolutionary status (see also Mallik 1999 and in this volume)[1]. Observations of Be and B in a few Hyades giants brought additional constraints on the processes that occur in the external layers of the A and early-F main sequence stars : In these giants indeed, Be is moderately underabundant (Boesgaard et al. 1977) while B is almost normal (Duncan et al. 1998) compared to the dilution predictions.

In A and F main sequence stars, atomic diffusion is known to play an important role (mainly in the very outermost stellar layers; see Michaud in this volume). However, diffusion theory alone predicts abundance anomalies much larger than the observed ones (Richer et al. 2000 and references therein). In particular at the age of the Hyades, radiative diffusion in stars with $T_{\rm eff} \simeq$7000K

[1]Let us note that the very low Li values found for the most massive subgiants are confirmed even when non-LTE effects are taken into account (do Nascimento et al. 2000)

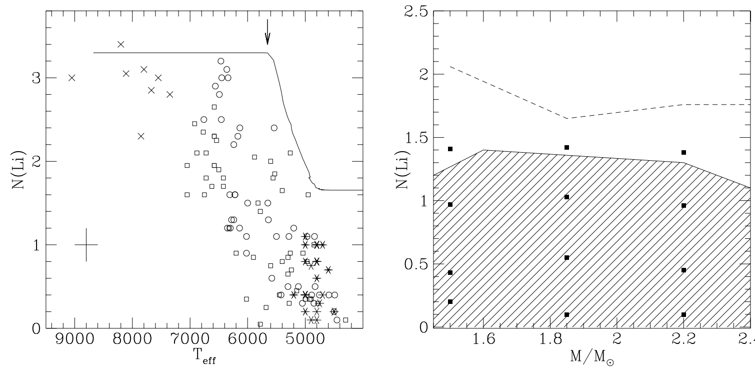

Figure 1. Li in stars with masses higher than 1.5M$_{\odot}$. **(left)** Hyades main sequence stars (crosses, Burkhart & Coupry 2000), field subgiants (circles, Lèbre et al. 1999; squares, Wallerstein et al. 1994), giants of open clusters (stars, Gilroy 1989). The solid line shows the evolution of the surface lithium with T$_{\rm eff}$ for a standard 1.85M$_{\odot}$ model (Charbonnel & Talon 1999, CT99); the arrow points the theoretical start of dilution. **(right)** Evolved stars of open clusters (shaded area). The dotted curve shows the Li values expected with dilution alone, i.e. no additional internal mixing on the main sequence. The squares give the Li values predicted when rotation induced mixing is taken into account as in CT99 for different rotation velocities of the main sequence star ranging between 50 and 150 km.sec^{-1}

should lead to important Li overabundances, while at T$_{\rm eff}$ >7200K strong Li underabundances should be due to settling. This is not observed. Some macroscopic processes thus occur, that both decrease the efficiency of the atomic diffusion and lead to non standard Li depletion in evolved stars as we discussed previously (see also Part II, Pinsonneault, Charbonnel & Deliyannis in this volume)

Charbonnel & Talon (1999, hereafter CT99) studied the combined effect of atomic diffusion and rotational mixing on the LiBeB in these stars up to the completion of the first dredge-up, in the framework of the transport of matter and of angular momentum by wind-driven meridional circulation and shear turbulence (Zahn 1992, Maeder 1995, Talon & Zahn 1997, Maeder & Zahn 1998). Their models were computed for rotation velocities covering the large Vsini range observed at these spectral types. While lithium is found not to vary much at the stellar surface at the age of the Hyades, more destruction occurs inside the rotating models compared to the classical ones and its signature appears at the surface before the onset of the dilution. The post dredge-up Li values are much lower than predicted classically and agree with the observations both in evolved stars belonging to open clusters and in the field, as can be seen in Fig.1. The less fragile Be and B are less affected than Li by the rotation-induced mixing, and the corresponding predictions also reproduce the observations in the Hyades giants (Boesgaard et al. 1977, Duncan et al. 1998). The main success of CT99 models which include the most complete description currently available for rotation-induced mixing is their ability to reproduce abundance anomalies of various elements over a large domain of stellar masses and evolutionary phases. Indeed the same treatment of the hydrodynamical process which can account for the C and N anomalies in B type stars (Talon et al. 1997) also shapes the hot side of the Li dip in the open clusters (Talon & Charbonnel 1998) and explains the LiBeB observations in main sequence F and A stars as well as in their evolved counterparts (CT99; see also Talon & Charbonnel in this volume).

2.2. Population II subgiants

The behavior of lithium in metal-poor field subgiants appeared clearly in the large sample of Pilachowski et al. (1993) and was confirmed recently by Gratton et al. (2000; see also Carretta et al. 1998). As can be seen in Fig.2, the observed trend (steady decline of lithium abundance with temperature decreasing between $\sim$ 5600 and 4900K on the subgiant branch) is well explained by the theoretical dilution up to the completion of the first dredge-up (e.g. Deliyannis et al. 1990, Proffitt & Michaud 1991, Charbonnel 1995). The precise temperature at which theoretical dilution begins is somewhat model dependent, but nonetheless, given current lingering uncertainties in the temperature scales, the agreement between theory and observation is impressive.

Pilachowski et al. (1993) noted that the lithium abundances in their subgiant sample showed more scatter than do the turnoff stars; they interpreted this as an indication for variations in the main sequence Li destruction below the observable surface layers. Reconsidering Pilachowski's sample to which they added some more stars, Ryan & Deliyannis (1995) showed however that much of the scatter disappears with a careful and self-consistent treatment of the reddening. Note that this difference does not show up in Gratton's sample. However, the PopII field subgiants with Li upper limits are presumably the counterparts of the few plateau stars with no Li detection (see Part II in this volume); both samples should be analysed simultaneously to understand and quantify a possible Li depletion in halo stars.

Very few data exist up to now for LiBeB in globular clusters. Lithium abundances have been determined for slightly evolved stars which have not reached the onset of dilution in NGC 6397 (Molaro & Pasquini 1994, Pasquini & Molaro 1996) and M92[2] (Deliyannis et al. 1995, Boesgaard et al. 1998). These turnoff stars with very similar effective temperature show a Li dispersion of a factor about two and three respectively in NGC 6397 and M92 (see Fig.2). Boesgaard et al.(1998) favor the explanation of differential depletion in M92 by rotation induced mixing in objects with different stellar rotational histories. It is worth knowing however that the M92 subgiants show other "surprising abundances" (King et al. 1998), i.e., under and overabundances respectively of Mg and Na compared to field stars with the same metallicity. While the observational data need to be confirmed, these anomalies reveal stricking field to cluster differences (see also §3) which could reflect environmental effects (pollution of the intracluster gas, distribution of the initial rotation velocities, ...) which have to be disentangled. This is of particular importance if one wants to use and com-

[2]The globular cluster stars were chosen to be pre-dilution stars, relative to the empirical commencement of the Li dilution from field stars

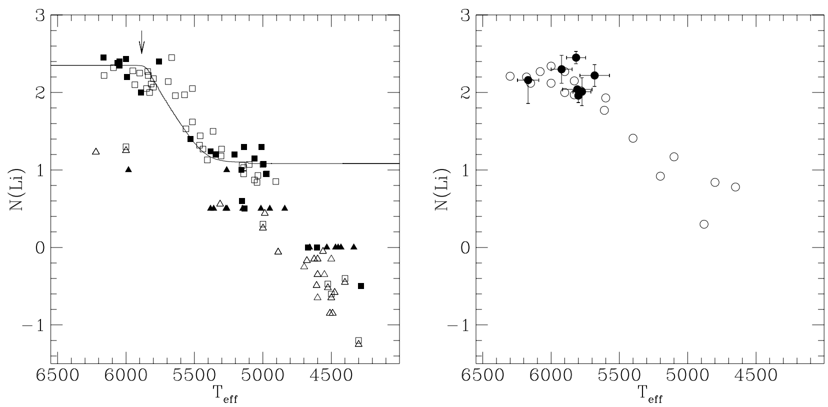

Figure 2. Li in metal-poor subgiants. **(left)** Field stars with $-2 \leq$[Fe/H]≤ -1 (Ryan & Deliyannis 1995, open squares and triangles for real detection and upper limits respectively; Gratton et al. 2000, black squares and triangles). The solid line shows the prediction of the Li variations due to dilution alone (which starts as indicated by the arrow) at the surface of a 0.8M$_\odot$, Z=10^{-4} star (Palacios et al. 2000). **(right)** Stars in globular clusters M92 (Deliyannis et al. 1995, Boesgaard et al. 1998, black points) and NGC 6397 (Molaro & Pasquini 1994, Pasquini & Molaro 1996); the values presented here were derived within Carney's temperature scale (Spite, private com.)

pare the Li data in globular cluster and halo stars to constrain the primordial abundance of this element and its evolution in the early epochs (see Part II).

3. LiBeB and ^{3}He on the Red Giant Branch

3.1. Evidences for extra-mixing in low-mass RGB stars

Observational evidences have accumulated during the last years of a second and distinct mixing episode that occurs in low mass stars when they climb the red giant branch (RGB; see Kraft 1994, and more recently Charbonnel et al. 1998, Sneden 1999 and Gratton et al. 2000 for references). The signatures of this non-standard process in terms of abundance anomalies are numerous. In metal-poor field giants, it leads to a further major decrease of the Li abundance (around 4800K as can be seen in Fig.2). By reaching the regions of incomplete CNO burning inside the RGB stars, it induces a decrease of the carbon abundance and of the carbon isotopic ratio, and a corresponding increase of the N. In most of the metal-deficient field and globular cluster stars, the surface ^{12}C/^{13}C ratio even approaches the equilibrium value; this anomaly also appears, while at a lower extent, in evolved stars belonging to open clusters with turnoff masses lower than $\sim$2M$_\odot$ (Gilroy 1989, Gilroy & Brown 1991). This extra-mixing is also frequently invoqued to explain the global O versus Na anticorrelation observed in globular cluster red giants (see Weiss et al. 2000 for references).

All the relevant data clearly indicate that the extra-mixing starts acting when the stars pass the so-called RGB bump in the luminosity function. At this point, the hydrogen burning shell (HBS) crosses the discontinuity in molecular weight built by the convective envelope during the dredge-up. Before this evolutionary point, the mean molecular weight gradient probably acts as a barrier to the mixing between the convective envelope and the HBS (Sweigart & Mengel 1979, Charbonnel 1994, 1995, Deliyannis 1995, Charbonnel et al. 1998). Above this point, this barrier disappears and the extra-mixing, whatever its nature, is free to act.

3.2. The origin of the extra-mixing ...

Several attempts have been made to simulate this extra-mixing in order to reproduce the abundance anomalies in RGB stars. Denissenkov & Weiss (1995) and Weiss et al. (2000) modelled this deep mixing by adjusting both the mixing depth and rate in their diffusion procedure, but focussed on the O-Na anticorrelation (see also Cavallo et al. 1998). Wasserburg et al. (1995), Boothroyd & Sackmann (1999) and Sackmann & Boothroyd (1999; see also Sackmann in this volume) used an ad-hoc "conveyor-belt" circulation model, where the depth of the "extra-mixed region" is related to a parametrized temperature difference up to the bottom of the HBS and is adjusted to reach the observed carbon isotopic ratios as a function of stellar mass and metallicity.

Some studies attempted to relate the RGB extra-mixing with physical processes, among which rotation seems to be the most promising. Sweigart & Mengel (1979) suggested that meridional circulation on the RGB could lead to the low $^{12}C/^{13}C$ observed in field giants. Charbonnel (1995) investigated the influence of such a process by taking into account more recent progress in the description of the transport of chemicals and angular momentum in stellar interiors : Zahn's (1992 and subsequent developments) consistent theory which describes the interaction between meridional circulation and turbulence induced by rotation (as already discussed in §2.1). This framework is appealing because it takes advantage of some particularities of the non-homologous RGB evolution. In particular, some mixing is expected to take place wherever the rotation profile presents steep vertical gradients, and near nuclear burning shells. Moreover due to the stabilizing effect of the composition gradients, the mixing is expected to be efficient on the RGB only when the hydrogen-burning-shell crosses the chemical discontinuity created by the convective envelope during the first dredge-up. Using a simplified version of this description Charbonnel (1995) showed that the rotation-induced mixing can indeed account for the observed behavior of carbon isotopic ratios and for the Li abundances in Population II low mass giants. Simultaneously, when this extra-mixing begins to act, ^{3}He is rapidly transported down to the regions where it burns by the $^3He(\alpha,\gamma)^7Be$ reaction. This leads to a decrease of the surface value of ^{3}He/H (see also Deliyannis 1995, Hogan 1995 and Sackmann & Boothroyd 1999).

The study of horizontal branch stars also provides some intriguing clues about angular momentum evolution on the RGB. Peterson (1983) first discovered that some blue horizontal branch stars are rapid rotators (see Behr et al. 2000 for more recent data and a discussion of the observational situation). Pinsonneault et al. (1991) noted that the combination of RGB mass loss, high horizontal branch rotation, and low main sequence rotation required strong differential rotation with depth in giants. If the convection zone of RGB stars had solid body rotation, differential rotation with depth in their MS precursors was also required. Behr et al. (2000) found a break in the rotational properties of HB stars, in the sense that very blue HB stars both exhibited the surface signature of atomic diffusion and rotated more slowly than slightly cooler stars. Sills & Pinsonneault (2000) interpreted this as evidence that mean molecular weight gradients caused by atomic diffusion inhibit angular momentum transport in hot horizontal branch stars; this is an independent test of the impact of composition gradients in a different evolutionary phase. In addition, Sills & Pinsonneault (2000) found that uniform rotation at the main sequence turnoff was only compatible with rapid horizontal branch rotation under the following conditions: (1)turnoff rotation of order 4 km/s rather than the 1 km/s inferred from an extrapolation of the Population I angular momentum loss law to Population II stars; (2)constant specific angular momentum in the convective envelopes of giants; (3)strong differential rotation with depth in the radiative cores of giants. All of these are radically different from the expectations from main sequence angular momentum evolution models, and they are an indication that further theoretical work is needed in physical models of RGB rotational mixing. It is encouraging, however, that all of the above properties favor more vigorous rotational mixing on the RGB than would be expected from the opposite conclusions.

3.3. ... and its consequences for ^{3}He

While there is a consensus on the fact that the mechanism which is responsible for the chemical anomalies on the RGB also affects the ^{3}He abundance (as first suggested by Rood et al. 1984), large uncertainties remain on the quantitative extent of this ^{3}He depletion. In the PopII models of Charbonnel (1995) ^{3}He decreases by a large factor in the ejected envelope material but low mass stars remain net producers (while far much less efficient than in the case of models without RGB extra-mixing) of ^{3}He. On the other hand the models of Sackmann & Boothroyd (1999) predict a net destruction of ^{3}He by low mass stars. Both studies also differ on the predictions for the evolution of the ^{12}C/^{13}C ratio at the stellar surface. While the rotation-induced mixing by Charbonnel reproduces the observed sharp drop of the ^{12}C/^{13}C just beyond the RGB bump and its constancy at higher luminosity, the cool bottom processing model by Sackmann & Boothroyd predicts a smooth decrease of the surface ^{12}C/^{13}C all along the RGB up to the tip where the low values are finally (but too belatedly compared to the data) reached.

As is customary, we can say that at this stage additional studies are needed. In particular, a consistent treatment of the transport of chemicals and angular momentum as decribed in §2.1 will prove most useful to quantify with confidence the impact of the rotation-induced mixing on the RGB. Work is in progress in this direction (Palacios et al. 2000).

The stake of this problem for what concerns the primordial nucleosynthesis and the galactic evolution of ^{3}He is discussed by Tosi and by Rood & Bania in this volume. Let us note that in a statistical study of the carbon isotopic ratio observed in post-bump RGB stars, Charbonnel & do Nascimento (1998) showed that at least 95 % of the low mass stars do undergo the extra-mixing. This thus leads to a strong revision of the actual contribution of low mass stars to ^{3}He evolution, and should account for both the measurements of ^{3}He/H in galactic H_{II} regions (Balser et al. 1994) and in the planetary nebulae (Rood et al. 1992, Balser et al. 1997).

3.4. The Li rich giants

If the ^{7}Be produced deep inside the RGB stars by ^{3}He burning could be rapidly transported to cooler regions before its electron capture to ^{7}Li can take place, fresh ^{7}Li could show up at the stellar surface. The so-called Cameron-Fowler (1971) mechanism due to the extra-mixing would thus have a chance to produce the so-called Li rich RGB stars (de la Reza and Charbonnel & Balachandran, this volume). Sackmann & Boothroyd (1999; see also Sackmann in this volume and Denissenkov & Weiss 2000) showed that certain assumptions, which depend critically on the speed, geometry and episodicity of their parametrized mixing, can indeed lead to important Li creation along the RGB. In particular high Li enrichment (up to logN(Li)=4) is obtained by Sackmann & Boothroyd (1999) with a continuous mixing which simultaneously induces a smooth decrease of the carbon isotopic ratio up to the RGB tip. As we discussed in the previous section this prediction for the ^{12}C/^{13}C ratio is not sustained by the observations and cast doubt on the underlying assumptions of the model. Moreover Charbonnel & Balachandran (2000; see also this volume) showed that the field Li rich stars are not observed all along the RGB, but that they do clump at the bump phase. This result fits well to the observations of the ^{12}C/^{13}C ratio which reveal a very fast mixing episode at the RGB bump (Palacios et al. 2000). Thus the Li-rich phase is extremely short, and its contribution to the Li enrichment of the ISM is certainly negligible.

3.5. Field-to-cluster differences

At this point, it is important to remember some striking differences which distinguish field and globular cluster red giants. In particular, while field giants show C anomalies but no O nor Na variations (indicating that the extra mixing does not reach the deep internal regions where the complete CNO cycling and the NeNa cycle occur), globular cluster bright giants exhibit the so-called universal O-Na anticorrelation (e.g., Kraft et al. 1993, Kraft 1994, Denissenkov et al. 1998) which could be of primordial origin or due to a deeper extra-mixing than in field stars. Up to now, observations in globular clusters are available only for some very bright stars close to the RGB tip (except in M13 for which very sparse data exist for stars close to the RGB bump) in very few globular clusters. Observations are crucially needed in less evolved stars down to the main sequence turnoff in order to quantify the primordial contamination of the intracluster gas by an earlier generation of more massive stars and to disentangle it from the real impact of in situ extra-mixing. In other words, the field-to-cluster differences have to be observationaly quantified and understood to constrain the physics and the efficiency of the extra-mixing in the advanced evolutionary phases.

4. Acknowledgements

C.C. thanks the Action Spécifique de Physique Stellaire and the Conseil National Français d'Astronomie for support. C.P.D. acknowledges support from the United States National Science Foundation under grant AST-9812735. M.P. would like to acknowledge support from NASA grant NAG5-7150 and NSF grant AST-9731621.

References

Alschuler, W.R. 1975, ApJ, 195, 649

Balachandran, S. 1990, ApJ, 354, 310

Balser, D.S., Bania, T.M., Brockway, C.J., Rood, R.T., Wilson, T.L. 1994, ApJ, 430, 667

Balser, D.S., Bania, T.M., Rood, R.T., Wilson, T.L. 1997, ApJ, 483, 320

Behr, B.B., Cohen, J.G., McCarthy, J.K. 2000, ApJ, 531, L37

Boesgaard, A.M. 1987, PASP, 99, 1067

Boesgaard, A.M., Deliyannis, C.P., Stephens, A., King, J.R. 1998, ApJ, 493, 206

Boesgaard, A.M., Heacox, W.D., Conti, P.S. 1977, ApJ, 214, 124

Boothroyd, A.I., Sackmann, I.J. 1999, ApJ510, 232

Brown, J.A., Sneden, C., Lambert, D.A., Dutchover, E. 1989, ApJS, 71, 293

Burkhart, C., Coupry, M.F. 1989, A&A, 220, 197

Burkhart, C., Coupry, M.F. 1998, A&A, 338, 1073

Burkhart, C., Coupry, M.F. 1999, private communication

Burkhart, C., Coupry, M.F. 2000, A&A, 354, 216

Cameron, A.G.W., Fowler, W.A., 1971, ApJ, 164, 111

Caretta, E., Gratton, R.G., Sneden, C., E., Bragaglia, A. 1998, in Paris-Meudon Observatory meeting, Galaxy Evolution : Connecting the Distant Universe with the Local Fossil Record, in press

Cavallo, R., Sweigart, A., Bell, R., 1998, ApJ, 492, 575

Charbonneau, P., Michaud, G., Proffitt, C.R. 1989, ApJ, 347, 821

Charbonnel, C. 1994, A&A, 282, 811

Charbonnel, C. 1995, ApJ, 453, L41

Charbonnel, C., Balachandran, S., 2000, A&A, in press

Charbonnel, C., Brown, J.A., Wallerstein, G. 1998, A&A, 332, 204

Charbonnel, C., do Nascimento, J.D. 1998, A&A, 336, 915

Charbonnel, C., Talon, S. 1999, A&A, 351, 635, CT99

Charbonnel, C., Vauclair, S. 1992, A&A, 265, 55

Denissenkov, P.A., Weiss, A. 1996, A&A308, 773

Denissenkov, P.A., Weiss, A. 2000, A&A, accepted

Deliyannis, C.P., 1995, in the ESO/EIPC workshop, The Light Element Abundances, Elba, 395

Deliyannis, C.P., Boesgaard, A.M., King, J.R., 1995, ApJ, 452, L13

Deliyannis, C.P., Demarque, P., Kawaler, S.D., 1990, ApJS, 73, 21

Denissenkov, P.A, Da Costa, G.S., Norris, J.E., Weiss, A., 1998, A&A, 333. 926

do Nascimento, J.D., Charbonnel, C., Lèbre, A., de Laverny, P., de Medeiros, J.R. 2000, A&A, 357, 931

Duncan, D.K., Peterson, R.C., Thorburn, J.A., Pinsonneault, M.H. 1998, ApJ, 499, 871

Gilroy, K.K. 1989, ApJ, 347, 835

Gilroy, K.K., Brown, J., A. 1991, ApJ, 371, 578

Gratton, R.G., Sneden, C., Caretta, E., Bragaglia, A. 2000, A&A, 354, 169

Hogan, C.J. 1995, ApJ, 441, L17

King, J.R., Stephens, A., Boesgaard, A.M., Deliyannis, C.P. 1998, ApJ, 115, 666

Kraft, R.P. 1994, PASP, 106, 553

Kraft, R.P., Sneden, C., Langer, G.E., Shetrone, M.D., 1993, AJ, 106, 1490

Lèbre, A., de Laverny, P., de Medeiros, J.R., Charbonnel, C., da Silva, L. 1999, A&A, 345, 936

Maeder, A. 1995, A&A, 299, 84

Maeder, A., Zahn, J.P. 1998, A&A, 334, 1000

Mallik, S.V. 1999, A&A, 352, 495

Molaro, P., Pasquini, L., 1994, A&A, 281, L77

Palacios, A., Charbonnel, C., Forestini, M. 2000, in preparation

Pasquini, L., Molaro, P. 1996, A&A, 307, 761

Pilachowski, C.A., Sneden, C., Booth, J. 1993 ApJ, 407, 699

Proffitt, C.P., Michaud, G. 1991, ApJ, 371, 584

Randich, S., Gratton, R., Pallavicini, R., Pasquini, L., Carretta, E. 1999, A&A, 348, 487

Richer, J., Michaud, G., Turcotte, S. 2000, ApJ, 529, 338

Rood, R.T., Bania, T.M., Wilson, T.L. 1992, Nature, 555, 618

Ryan, S.G., Deliyannis, C.P. 1995, ApJ, 453, 819

Sackmann, I.J., Boothroyd, A.I. 1999, ApJ510, 217

Sneden, C., 1999, 35rd Liège Int. workshop on The Galactic Halo - From Globular Clusters to Field Stars, in press

Sweigart, A.W., Mengel, K.G. 1979, ApJ, 229, 624

Talon, S., Charbonnel, C. 1998, A&A, 335, 959

Talon, S., Zahn, J.P., Maeder, A., Meynet, G. 1997, A&A, 322, 209

Vauclair, S. 1991, Evolution of Stars : The Photospheric Abundance Connection, IAU Symp. 145 (eds G.Michaud & A.Tutukov), 327

Talon, S., Zahn, J.P. 1997, A&A, 317, 749

Wallerstein, G., Böhm-Vitense, E., Vanture, A.D., Gonzalez, H. 1994, AJ, 107, 2111

Wasserburg, G.J., Boothroyd, A.I., Sackmann, I.J., 1995, ApJ, 447, L37

Weiss, A., Denissenkov, P.A., Charbonnel, C., 2000, A&A, 356, 181

Zahn, J.-P., 1992, A&A, 265, 115